CURVES OF EQUAL LOUDNESS WITH OCTAVE-FILTERED SOUND IN A DIFFUSE SOUND FIELD

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16. Abstract

After an introduction on the definition of loudness and its measurement, an apparatus for measuring curves of equal loudness with noise passed through octave filters and the mode of operation of the equipment is described. Especially the behavior of the persons taking part is discussed. The possibility of introducing a "noise level meter" with data taken in a diffuse sound field, which show a fall of about 3 dB per octave, is also discussed.

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1. Motive for the present investigation

The quantitative determination of sounds and the establishment of the optimum allowable sound levels are effected at present /65
by two methods.

The first, and older, method consists of the measurement of a given sound level with the aid of a system sensitive to the whole audible spectrum; this receiving system is constructed so as to mimic as closely as possible the response of the human ear and its "weighting" of the individual regions of the audible spectrum. This apparatus is known in America as a "sound level meter." In Germany, however, this nomenclature is more usual for an apparatus which weights all frequencies evenly in the area of interest. Since the curves of equal loudness for frequency-weighting are taken as a basis for the first-mentioned apparatus, it is known in Germany as the "DIN* - Loudness Meter" and measurements made with it are suffixed by the word "DIN - phon." [1]

The DIN - Loudness Meter and its determination of each sound in terms of a single number has the undoubted advantage of simplicity. This simplicity, though, must unfortunately be abandoned at one point. The DIN Loudness Meter originated from the demand for an apparatus to measure the loudness of pure tones in an evenly advancing sound field. Curves of equal loudness obtained in this way, however, are dependent on the loudness level. In order to take into account, to some extent, the dependence on

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[*DIN = Deutsche Industrie Normen = German Industrial Standards.]

on the amplitude of the frequency change, an international agreement was made, in which three different "weighting curves" were introduced, each for a particular sound level. This, however, has the great disadvantage, that--especially at low frequencies--different results are produced according to which curve is used. The uncertainty which resulted for the experimenter was reduced as much as possible by establishing the rule that the higher value was to be decisive in measurement. In the interest of noise-control, there was a tendency to value sounds rather too high than too low. More recently, this principle has been abandoned. The 3 curves are considered as equally valid. Therefore, each value given must be accompanied by an indication of which curve it was obtained from. Thus it was suggested that the curves be denoted as A, B, and C, and the corresponding values as dB_A, dB_b, dB_c.

It is very questionable whether this complication is worthwhile. Firstly, noise measurements concern themselves primarily with high loudness levels; thus one curve may already be useless. Over and above this, it must be stressed that the above division of the frequency spectrum into particular differently weighted regions is valid only for single pure tones. As soon as several /66
tones or a wide-band sound come into question, there is no way to determine the proper weighting curve except from the <u>over all</u> sound level. It is very likely that in this way a component will be weighted by a curve valid only for a much higher level.

The fact that such a n apparatus cannot estimate the various frequency-regions separately, as, in fact, the ear <u>can</u>, is shown in a much greater discrepancy between loudness-levels measured in this way and the loudness-levels. This discrepancy is noticeable in the fact that the more wide-band the noise measured, the more the DIN-loudness-level reading will be under the true level [2].

In the second method, one tries to give a true picture of loudness-level from sums of loudnesses of single frequencies ([3]-[9]) Attempts at this have led, however, only to relatively laborious calculations, and not to any sort of apparatus that was useful for practical measurements in industry or other fields.

Furthermore, the practice has grown up recently of constructing a so-called "Octave Level Diagram" in addition to the visually-given DIN-loudness levels for stationary noises. Technically, this requires no more than the introduction of octave-filters into the transmission path of the DIN-loudness meter; by this procedure, the weighting curve is replaced by an equal weighting of all frequencies, as in a sound-pressure meter.

If one has such an Octave-Level-Diagram, the question of allowable levels may be easily decided through comparison of the measured curve with a "desired curve" or "ideal curve." This procedure has been used, for example, in building acoustics, in the adjustment of shielding apparatus for damping the sound of footsteps on ceilings. The "ideal curve" does not take into account only the differential sensitivity of the ear to high and low frequency-regions. In that case, the curve would still be arbitrary, for it must also take into account the nature of the sound-stimulus. It concerns itself also with the fact that it is much easier to combat high frequencies than low frequencies.

Furthermore, it is not required for an allowable level that the measured curve lie at all points under the ideal curve. More practically a small excess of 2dB is allowed; however, areas where the measured curve lies below the ideal curve are not to be taken as compensating for areas of excess. This principle has the advantage that the question of allowable levels is always based on several points of measurement, and thus the rather low accuracy of acoustic measurements is not of great consequence.

Such comparison of curves has also been suggested in other areas, so that the admissibility or non-admissibility of certain sounds may be determined from their excesses in the "Octave-Level-Diagram." Often an excess of only one frequency is regarded as inadmissible. These curves, too, must take account of factors other than merely the peculiarities of the human ear. Here, also, one might take into account the present state of technology, obtaining then for each particular situation a corresponding "ideal curve."

L. Cremer and E. Lübcke, in a report on ideal normal curves for the classification of sounds to the Industrial Committee on "Loudness and Noise Measurements," have suggested the setting-up of a universal curve on the basis of curves of equal loudness. At the same time it was stressed that the known curves of equal loudness are not suitable for such purposes, because they were obtained from pure tones, and because they were obtained in a sound field advancing evenly toward the observer with a fixed angle of incidence. This extreme case is much more seldom seen in noise control, however, than that of a statistical distribution of frequencies and angles of incidence.

In this case, however, it is necessary to use only "white" noise, with an equal distribution of energy per Hz. It may be assumed, moreover, that all sound spectra whose fall in amplitude with frequency is less steep than that of the corresponding filtering in the ear, are weighted in an approximately equivalent way by the ear.

For many of the above reasons, the above experimenters have realized that it is desirable to measure curves of equal loudness with octave-filtered sound. L. Cremer, in the session of May 28, 1956, reported on his first set of experiments, which took place in the small echo chamber of the Heinrich Hertz Institute, a diffuse sound field. These unfortunately suffered greatly from technical defects and machine noises in the building.

In the meantime, experiments were being carried out in the echo chamber of the acoustical facility of the Institute for Technical Acoustics of the Technical University of Berlin - Charlottenburg; here conditions were more favorable, and the apparatus was radically improved, so that the investigation may be considered henceforth as favorably terminated.

In addition to this, S.S. Stevens [9] has obtained a curve of equal loudness with filtered noise in a diffuse sound field. In his publication he has also made use of a similar measurement by F.G. Tyzzer. Finally, similar comparative measurements have /67
been made by G. Jahn [12] at the Institute for Electrical and Building Acoustics of the Technische Hochschule, Dresden, who has most kindly communicated his incomplete results to us. Since his final report is not yet in our hands, this paper will not enter into a discussion of his results.

2. Experimental Procedure

2.1. Measurement Procedure

The curves of equal loudness with pure tones were ascertained by feeding alternately the reference tone and the tone to be compared (comparison tone) to both ears in an even sound field. The experimenter then adjusted the comparison tone so that it was either "equally as loud" as the reference tone, or so that it was either "louder than" or "softer than" the reference tone. Both procedures are possible, but the second is more practical. The adjustment for "louder than" and "softer than" fatigues the test subject less than the adjustment for "equally loud." If this method is used to determine curves of equal loudness with octave-filtered sound, then it becomes necessary, in order to grasp the idea of "loudness" properly, to compare each octave with a 100-Hz tone as reference. It is still extremely difficult, however, to subjectively compare two sound-events of different character, such as are presented by pure tones and filtered sound. For this reason, the reference tone of 1000 Hz was replaced by a third-filtered noise (i.e., a band of sound a third wide) around 1000 Hz.

The third around 1000 Hz, according to R. Feldtkeller and E. Zwicker [7], corresponds to a cluster of frequencies at this point in the audible range. Through this method it is possible, if necessary, to combine our results with those obtained by Feldtkeller and Zwicker, in order to shed new light on the response of the ear to noise.

Each separate measurement began with a briefing, as exact as possible, of each subject on the idea and goals of the experiments, and on the duties of the subject during the experiment. The various sounds were presented to the subject; the subject was given especial opportunity to hear the third-band around 1000 Hz, the comparison sound for the whole experiment, and familiarize himself with it for extended periods.

For a short period the third-sound and an octave-wide sound (average frequency 1000 Hz) were presented to the subject. The level of the 1000 Hz octave-band was slowly lowered, stepwise.

During the presentation, the standard level (of the third-sound) remained constant. The subject was then called upon to give a signal when the octave-sound (1000 Hz) seemed softer than the third-sound. At that point, the level of the octave-sound was again raised, until the subject gave a further signal indicating that the octave-signal seemed once more louder than the third-sound. Finally the level was again lowered, and so, continuing, the level of true "equal loudness" was gone through three times.

If one records the Maxima and Minima so obtained on a recording sound level meter, one may later determine the true level of "equal loudness" of sound by proper evaluation of the levels obtained. (Figure 1).

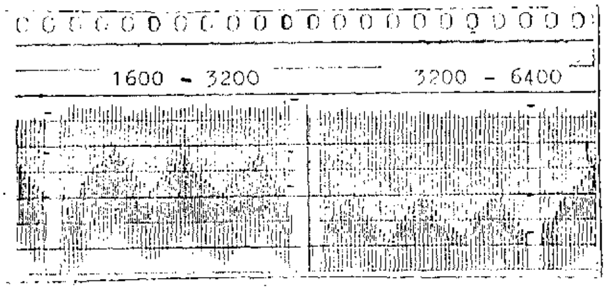

Figure 1. Example of a recording-level-meter diagram used for further work-up.

After every seventh "adjustment" of the level with the subject, (3rd minimum), a pause was taken and thus eventually the other points of a curve--at the average frequencies of the other octave bands--were obtained using the same procedure of short pauses. Here the series of points to be measured was so arranged, that, starting from the first third-band (at 1000 Hz) the high frequencies were first covered, and then the lower regions. A greater or lesser number of repetitions of measurements was made, according to the reliability and certainty of the subject's judgment.

As a proper duration for presentation of individual sound events in the diffuse sound field (echo chamber) our procedure indicated a time of 1.5 to 2 seconds. In addition to this, a short pause of 0.5 to 1 second was introduced between separate signals, so that there should be no overlap or intermixing of different sounds through the reverberation of the room.

The total time between reversals of the amplitude level change of between 2 and 3 is a compromise between the time it takes the subject accurately to ascertain the loudness of a given sound, and the time allowable immediately afterward, so that in the sub- /68
sequent comparison, the subject may still have in mind the level of the previous sound.

Within this limit, the most favorable time must be determined for each subject at the beginning of the measurement period.

Taking a curve by this method requires about 15 to 20 minutes. After such a time, usually, the accuracy and concentration of the subject were so far exhausted that a long pause was necessary. After obtaining 2 further curves, the measurements had to be ended. Thus, in one session, one could obtain only 3 curves. The complete measurement was usually divided into 3 sessions. In the first curves at the level of 70, 80, and 90 dB were taken, and in the second curves at 50 and 60 dB. Measurements at 50 and 60 dB could be obtained only at night; in the daytime, extraneous noise levels in the echo chamber reached 50 dB. In the night sessions, the danger of tiredness of the subject was, naturally, great. This danger was countered to some extent, by reducing the sessions to the measurement of only two curves.

2.2 Discussion of the experimental procedure and the conduct of the subjects.

With measurements such as these we have attempted to answer the following question: whether the data obtained from a sound stimulus of a definite nature, and its further development are subject to recognizable laws, and, if this is true, what these laws are; also, whether they are limited to single individuals, or are of general validity.

Only rarely is it possible quantitatively and qualitatively to determine the effect of a physical occurrence on the human in a direct manner--for example, in the way that an involuntary bodily reaction to a stimulus is measurable. Usually one is forced to regard the human as a more or less distorting "measuring instrument," whose indications are often obscure. If one is interested, not in unconscious reactions, but in man's capability of estimating conscious reactions and, further, his capacity for transmitting these to others in words or signs, then yet another psychologically conditioned transformation of the original "measuring experience" comes into the picture.

In a measurement as conducted here there are two principal sources of errors:

1. The uncertainty of the physical reaction and its fluctuations.

If it is possible to exclude persons with abnormal hearing from participation in the experiment, then the error resulting herefrom will be small enough to be treated as merely an experimental error, as with any measuring instrument. It can then be treated according to the usual guidelines for experimental error. (It is not always possible to determine with certainty whether the subject is useable, i.e., whether the hearing is normal, or whether the auditory powers have been weakened or altered through disease.)

2. The psychologically conditioned alteration of the primary reaction

This error may be so diverse in its manifestations and so insidious in its power that one is forced continually to observe the subject, and to set up the experimental procedure so that the experimenter may continually direct his attention to this error.

We will here treat more closely some of the most commonly observed errors.

1. In a comparison of the third-sound with an octave-sound lying close in frequency, the actual alteration of the level of the octave-sound is ascribed by the subject to an imagined change in the level of the third-sound; for example, a lowering of the octave-sound level is often perceived as a raising of the third-sound level with a constant level of the octave-sound.

It may be helpful to have the subject attempt to compare fairly unlike sounds at the beginning of the experiment, in order to accustom himself to the work. One objection to this, however, is that the comparison of loudnesses of extremely different character is extremely difficult for untrained persons at the beginning, and so they may become unsure of their perceptions.

2. Often the subject was, at first, unable to make reasonable decisions between "louder than" or "softer than" the third-sound. Often the distance between the maxima and minima was too small, occasionally too large. In training the subject the following instructions were given: that the octave-sound must

seem with <u>certainty</u> to be louder or softer than the third-sound.

3. After a certain time, the subject will begin to expect that every time he gives his signal, the change of sound level will reverse its direction. If the level-change proceeds in unvarying, constant, small steps, then the first step that ensues <u>after</u> the reverse in direction will not correspond to the step that is (unconsciously) expected; it will be much smaller. This may lead to the subject's thinking that his signal has been misunderstood, and that no reversal has been made in the level-change. The signal may then be unnecessarily repeated, leading to harmful confusion in the course of the experiment.

4. The subject becomes conditioned to the rhythm of the measurements. This occurs primarily in connection with the following points: /69

a) The frequency of direction reversal (of change in sound level).

It is desirable to vary this reversal frequency, so as to counteract the fatigue induced in the subject by too great regularity. However, as mentioned above, any variation in this frequency is so poorly tolerated that it is better to take no account of this fatigue and deal with it as best as possible in other ways.

b) The rhythm of the level change.

The subject will become accustomed to the fact, for example, that after 5 reversals the Octave-noise is always too loud or too soft. He then gives the signal from the conviction that the Octave-signal <u>must</u> be too loud or too soft and not from an objective determination. The regular progress of the level change must therefore be changed or interrupted; however, only to the extent that any reaction of the subject to this alteration remains insignificant.

(c) The succession of different octave-noises

It has been our experience that it is not good to exactly follow the above-given sequence of measurement points; a better procedure is as follows: at the beginning of each measurement point the subject is presented with the new noise at an unexpected level (much too loud or much too soft), and is asked, as a starter, to equalize approximately the levels of the two noises, that of the previously unexposed sound-region and the standard. If the unfamiliar sound is presented at a level too close to the correct one, this may be uncritically accepted by the subject as equality.

For the sequence of measurements we have found the following quite favorable:

Daytime:	80, 70, 90 dB.
Night-time:	60, 50 dB.

One must consistently take care to plan an experimental procedure that, on the one hand, obviates any danger of habit forming as described above, and, on the other hand, leaves enough regularity so that the subject does not become confused; the problem of fatigue is also of greatest importance.

5. The subject must remain as free as possible from optical stimuli and should be in a neutral environment. New and strange impressions may divert the attention.

A comfortable chair, a table, and a cozy lamp, which lights up only the subject and the nearest surroundings, but leaves the rest of the room in darkness, will create a comfortable atmosphere.

6. The various sounds, especially at low frequencies, may take on a somewhat snarling quality in association with the third-noise, and give rise to various associations. Such things may also come to pass for noises which remind the subject of personal experiences (e.g., wind-noises during a railway trip, and so on.)

This may go so far that the subject forgets his surroundings and his task entirely, and falls asleep; extra-ordinary as this may seem to those who have not done such experiments.

7. Many subjects tend to lighten their task through various imaginings, which connect with the noises or the change of the noises.

Two examples:

a) If one imagines for each sound a source or object as creator, then one may think that, with changes in level of the received sounds, the position of the imagined source is moving. According as the source of the octave-sound seems closer or farther away than that of the third-noise (in the inner eye of the subject), the subject may assume that the sound is louder or softer.

b) If one imagines music with the sound which is written in 2/4 or 4/4 time, one may so order two adjacent sounds that the heavy beat [down-beat] corresponds to the louder and the light beat to the softer.

If now the previously softer noise suddenly becomes the louder, a rhythmic "leap" is suddenly introduced into the music--a half-measure seems to be missing.

This is a very sensitive reaction, whose point of occurrence is easily recognizable. If the subject assumes, further, that this point is identical with the perception of "louder than" or "softer than" the third-noise, at which point he is supposed to give his signal, then he will tend to concentrate, not on the true changes in loudness or softness, but on the music which he imagines to himself.

The extent to which such aberrations may be tolerated must be left up to the individual judgment of the experimenter.

The number of people that took part in these experiments was necessarily limited by the facilities of our Institute. Furthermore, we laid more weight on obtaining the most exact possible measurements with a smaller number of persons, than on combining a great number of individual results: The following people took part: Fellows of the Institute, students, on whom this duty was incumbent as part of their education, and friends and acquaintances of the experimenter, who had the kindness to put themselves at his disposal. Various peculiarities were observed in these different classes of people.

Fellows of the Institute were usually familiar with the situation and the test procedure; but were, however, often biassed by their superior knowledge with regard to the results of the experiment. /70

Students often find the duties of the experiment wearisome, and wish to complete the session as quickly as possible, in contrast to the participants mentioned above, whose eagerness to end may often be controlled.

Musically trained persons were the sharpest and most accurate observers. Participants trained in medicine or having knowledge of the difficulties of electro-acoustic measurement often were unable to concentrate on the duties given to them; firstly, because they denied the validity of the measurements from physiological considerations, and secondly, because they lost concentration on their tasks while searching for flaws in the apparatus or other aspects that might be criticized.

3. The Apparatus

Figure 2 is a schematic diagram of the various components.

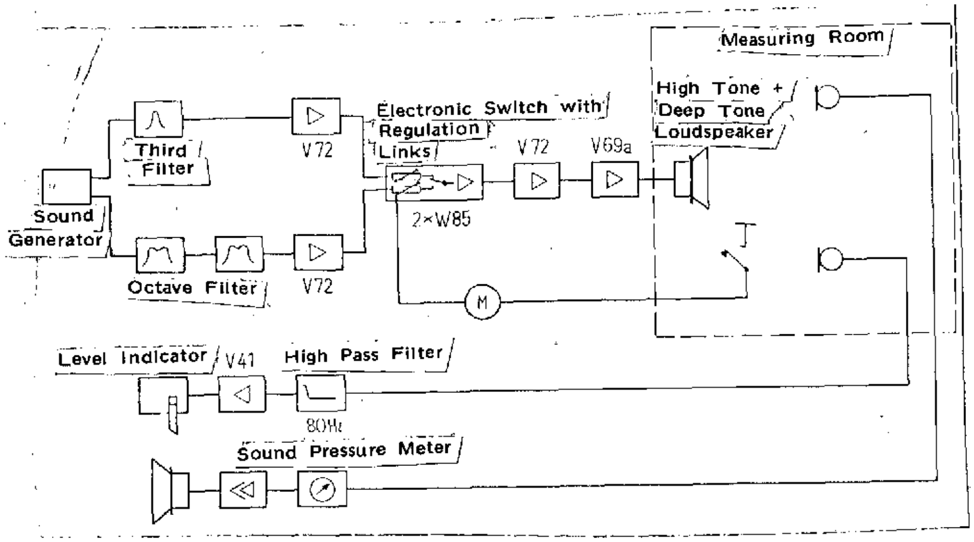

Figure 2. Block diagram of the apparatus.

Two signals are taken from a white-noise generator. The first is run through a third-filter, which passes the frequencies 900 - 1120 Hz, next through a matching amplifier and a control element, and is finally led to an electronic (non-mechanical) switching device.

The second signal is first passed through any of the following octave filters, as desired:

100	-	200	Hz
200	-	400	Hz
400	-	800	Hz
800	-	1600	Hz
1600	-	3200	Hz
3200	-	6400	Hz
6400	-	12800	Hz

then (as before) through an amplifier and a control unit to the electronic switching unit. This last device switches between the two signals in a noise-free manner (i.e., without any clicks or "pops") and delivers one of them to a second amplifier and a power amplifier, and finally to the loudspeaker system arranged in the measurement room.

The sound pressure produced in the measurement room may be measured in two ways. First, through a sound pressure meter (type EZGN from the company Rohde and Schwarz, Munich). This permits adjustment of the third-noise to the required absolute level for the measurement of each particular curve. The second measuring apparatus measures the difference between the sound pressure of the third-noise and the sound pressure of the octave-noise. It consists of a measuring microphone, a high-pass filter, an amplifier, and a recording-level-meter. The control element for the octave-sound is operated by the experimenter by means of a button accessible to him.

Details of the circuit:

The switching from one signal to the other is done through suppression of the undesired signal by means of a high negative grid bias. Through the usage of suitable electronic switching elements one can insure that this blockage is both put in and taken out in a gradual manner, without any sudden changes.

Data for frequency-change and for distortion factor are the usual for such equipment.

Data for the switching-suppression:

Approx. 90 Db decrease in 50-100 ms
Increase to U_{max} in 50-500 ms   } as desired

The switch is operated with the contact c_1 and d_1 or by hand with the keys T_3 and T_4 (which may be locked in the test room). (See Figure 3).

It was found necessary for the experiments that the experimenter be as free as possible from any mechanical operations, especially the adjustment of the level of the octave-sound. The entire attention of the experimenter must be focused on the subject.

A supplementary relay system was constructed which permitted the following: (See Figure 3)

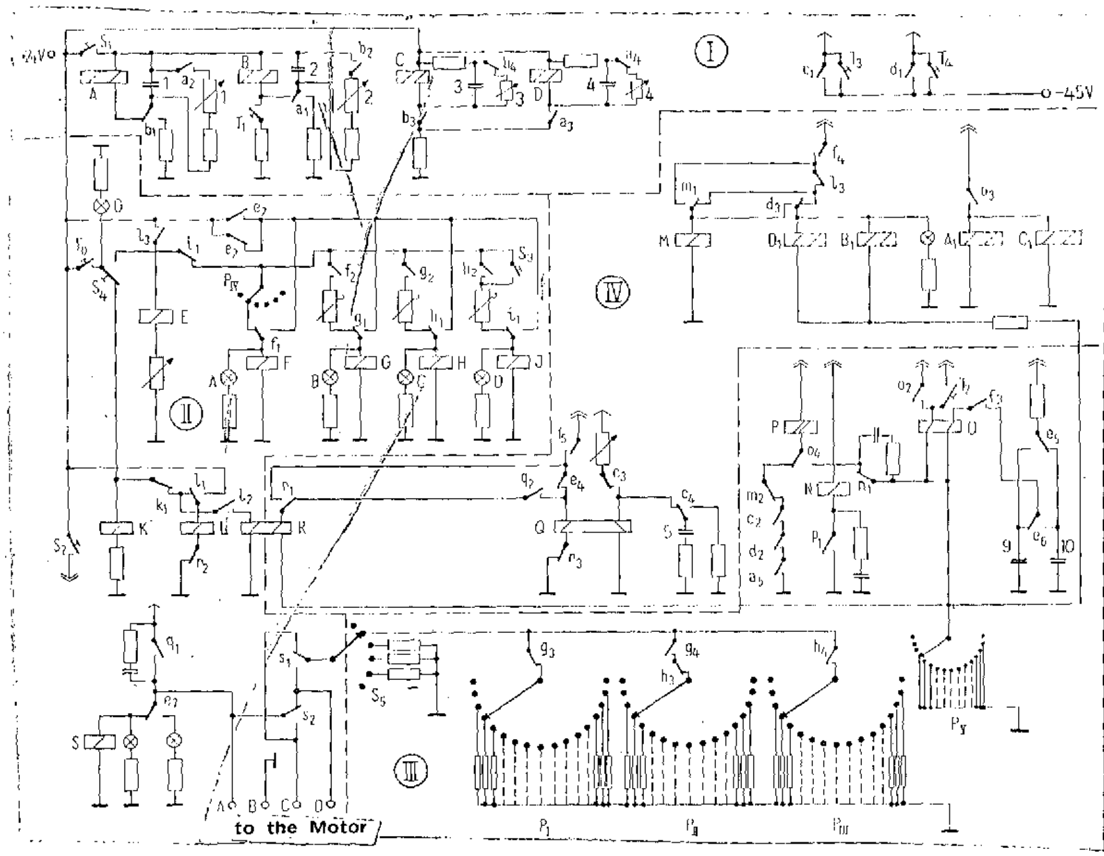

Figure 3. The relay "steering" mechanism

I. Automatically working "reversal" control

II. Counting apparatus and motor-reversal apparatus

III. Motor speed control

IV. Automatic stopping controls

1. Switching from signal 1 to signal 2 and the reverse, with various durations of 0.5 - 5 sec. The switch is controlled by two relays (A and B) which work in alternation. The relays are /71 energized until the capacitors 1 or 2 have discharged through them. During the "rest period" the capacitors are charged up again. The discharge may be hastened by auxiliary parallel resistances (3, 4)

and by the potentiometers 1 and 2. Thus the working periods of relays A and B may be adjusted within the given time limits.

2. Introduction of pauses between the "reversals" with variable durations of 0.2 - 2 sec. C and D operate dependently on A and B. The opening of C and D may be retarded by the potentiometers 3 and 4 in conjunction with the associated circuitry, between given limits. Through the overlapping of the "on"-periods of relays C and D arise the pauses between the periods when either one signal or the other is being produced in the text-chamber.

3. Automatic motorized operation of the first control unit. The control can be operated in variable steps according to a previously established plan via a selectable system of contacts.

Thus we achieve the following: that after a reversal in the direction of level change, the next reversal point is approached, first in large steps, and then in progressively smaller ones, as the point is approximated. This has 3 advantages:

a) Time is saved; the next turning-point is reached as quickly as possible.

b) The exactness of measurement is facilitated by the approach in small steps when close to the particular maximum or minimum; also, it becomes unlikely that the true point of perception of "louder than" or "softer than" will be overreached by too large gradations of level.

c) Large level changes immediately after the subject's giving his signal will prevent the above-mentioned impression that the direction of level change has not reversed.

One may make full use of the various possibilities of the selectable contact system so as to achieve the optimal rates of level change after each particular maximum or minimum.

4. Automatic reversal of direction of level change through a signal from the experimenter.

5. Automatic stopping of the relay system and simultaneous suppression of both signals (Pause) after 6 or 8 "reversals" as desired by the experimenter. /72

4. Measurements and Their Results

4.1. Results in the echo chamber with octave-filtered sound

At first, experiments were carried out with regard to the comparability of various filtered sounds, the size of the allowable distortion factor, the length of measurements, accuracy and certainty of the apparatus, and conduct and situation of the subject. The subject often finds it very difficult to compare sounds of widely differing frequencies. In order not to distort inadmissibly the large peak-values of the sounds, that is, to keep the distortion factor under 1.5%, all equipment was run -10dB below the maximum input.

4.1.1. Experimental Setup

For measurements in the diffuse sound field an echo chamber of triangular cross-section and sloping room was available. No room surface was parallel to any other. The volume of the echo chamber was 118 m^3.

It is important for the experiment that all frequencies have, as closely as possible, the same reverberation period. Furthermore, it is necessary that the sound-field be equally distributed in all directions.

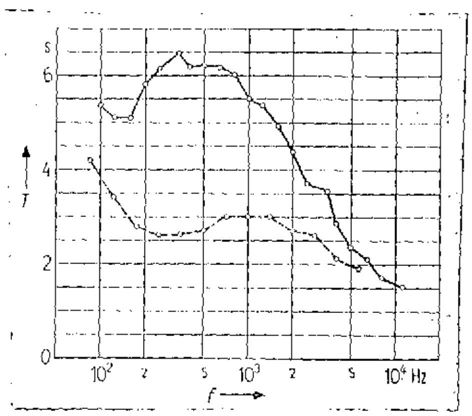

Figure 4. Reverberation period of the chamber used for measurement (_______) untreated; (-----) treated.

In Figure 4 we see the reverberation period of the untreated and treated room plotted against the logarithm of frequency. The rise in the reverberation period below 100 Hz is unimportant, since our lowest frequency was 100 Hz. To achieve a reverberation period that changed as little as possible with frequency, and satisfactory diffuseness, we placed tuned resonators for lower frequencies and perforated boards for middle frequencies in statistical distribution on the boundary-surfaces of the chamber. No special measures were used to promote diffuseness. When the room was filled with white noise, variations of only $\pm$ 1 dB in level were found in the neighborhood of the measurement position.

For diffuseness the sound source must have no pronounced directionality. As a woofer a corner speaker was used, and for high frequencies a Polyeder with 12 separate systems. The subject sat in a place of his own choosing; all subjects confirmed that the location of the sound source was not evident or assignable.

4.1.2. Results

In all, 47 persons were available. Six of these were rejected, since they were either abnormal in hearing or were not able to estimate loudnesses. The results from 41 persons were worked up. Six persons were used for the measurements of the curves for 50 and 60 dB effective sound pressure of the third-noise around 1000 Hz, 27 for the 70, 80, and 90 dB curves, and 8 for the 50, 60, 70, 80, and 90 dB curves.

The standard least-squares deviation of the standard level, calculated according to the relation

gave s = $\pm$ 2.8 dB

Table 1 Curves of equal loudness with octave-filtered noise. Values obtained from experimental results in diffuse sound field.

Oktaven	Terz um 1000 Hz				
	50 dB	60 dB	70 dB	80 dB	90 dB
100 bis 200 Hz	56,5 dB	65,7 dB	73,9 dB	81,7 dB	91,4 dB
200 bis 400 Hz	52,9 dB	62,4 dB	72.7 dB	81,0 dB	91,5 dB
400 bis 800 Hz	49,4 dB	59,5 dB	69,8 dB	77,9 dB	88,0 dB
800 bis 1600 Hz	46,2 dB	56,7 dB	67,0 dB	76,3 dB	85,9 dB
1600 bis 3200 Hz	40,0 dB	49.3 dB	61,0 dB	70,2 dB	79,0 dB
3200 bis 6400 Hz	38,0 dB	46,5 dB	60,0 dB	68,3 dB	76,7 dB
6400 bis 12800 Hz	35,5 dB	44,5 dB	50,5 dB	67,3 dB	75,9 dB

Figure 5. (————) Curves of equal loudness with octave-filtered noise in diffuse soundfield. (--------) Approximation of the loudness curves with straight lines with fall-off of 3 dB per octave; also suggestions for frequency curtailment outside of the measured area.

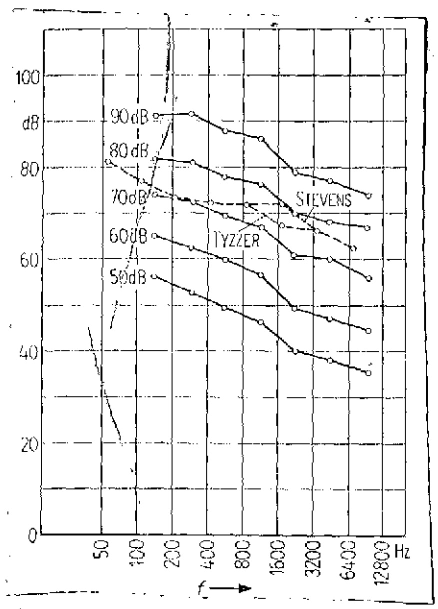

Figure 5 shows the results of the curves of equal loudness /73 with octave-filtered noise in diffuse sound field (in Table 1 the values themselves are given). This shows, first, that they have a substantially different character from the known curves of equal loudness, which are obtained with pure tones advancing in even waves toward the observer in a dead room. All five curves obtained run approximately parallel. The portion of the 70 dB curve between 100 and 200 Hz (avg. Frequency 142 Hz) presents an exception. This octave was not unequivocally comparable with the third around 100 Hz. With a few exceptions, the subjects made the assertion, for this curve, that they felt pain in the ear. Thus the measurements made were not entirely the estimation of a loudness, but also of the pain boundary.

5. Discussion of Results

The most striking conclusion that may be drawn from the results brought together in Table 5 is the following: that up to the highest frequency measured here--the octave from 6400-12800 Hz and the average frequency of 9000 Hz [illegible]--no further increase in level, i.e., no decrease in the ear's sensitivity, was observable.

This result is in accordance with that of S.S. Stevens for a curve observed at 73 ab, shown in Figure 5 in broken lines.

The fact that this curve is not precisely parallel to the ones obtained in our experiments may be ascribed to certain variations in the experimental conditions; it may also be taken as an indication of the unavoidable variations of measurements of this nature.

With regard to the utilization of these curves, it is not suggested that all their variations in slope be taken as significant, even though some of these fluctuations appear in all the curves. It seems more sensible to simplify the results by approximating the curves with straight lines which decrease by 3 dB per octave. These straight lines are shown in Figure 6.

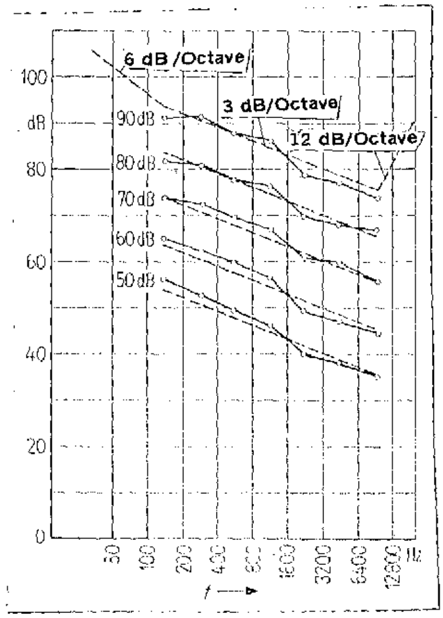

Figure 6. (———) Curves of equal loudness with octave-filtered noise in diffuse sound field.
(------) Approximation of the loudness curves with straight lines with fall-off of 3 dB per octave; also suggestions for frequency curtailment outside of the measured area.

It is very significant that these approximations may be treated, with equally good accuracy, as parallel lines; and that, also, in the area of the most useful technical levels, no dependence of the estimated curves on loudness-level is seen.

This fact allows us to suggest a further simplification of the DIN-loudness meter, whose principal advantage is its simplicity: namely, a reduction from three estimating curves to one. According to our results, moreover, the estimating curve would be considerably simpler than those heretofore in use: a straight line with a descent of 3 dB per octave in the region 125-9000 Hz. Measurements had to be cut off above and below this frequency region. Here, also, practical considerations will dictate the use of simple "straight-line" laws, always keeping in mind, however, that subjective measurements in these borderline areas are difficult to obtain.

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At high frequencies, of course, the question of the frequency-cutoff point depends greatly on the age of the subject. There appears to be no reason why one should restrict oneself entirely to old, or entirely to young people. As a preliminary guidelines we may suggest here that a decrease in sensitivity of at least 12 dB per octave is probably, which would show up in the stright-line diagram (Fig. 6) as a corresponding rise.

Below 125 Hz, experimental accuracy suffers from the unavoidable production of overtones. Here, too, the decrease in sensitivity per octave will undoubtedly be above 3 dB. According to the measurements of S.S. Stevens and F.G. Tyzzer it appears proper to postulate a fall-off of 6 dB per octave in the range 125-62 Hz, again visible as a corresponding increase on Figure 6; for technical reasons, one may allow for an even steeper fall-off in sensitivity, which appears allowable also in view of hearing considerations.

Levels established with a wide-band estimating level meter such as this may be distinguished from the so-called DIN-loudness levels, we suggest, by calling them merely "sound levels." The appellation "level" says very clearly that the measured values (as also with the DIN-loudness meter) are more closely related to the sound-pressure level than those loudnesses obtained by a subjective comparison with the 1000-Hz tone.

As reference pressure for this level system one must, of course, use the internationally defined threshold value of $p_0 = 2 \times 10^{-4}$ m bar, as with the sound-pressure level meter and the DIN-loudness meter.

It is also not necessary to qualify the noise-level values with anything else than dB. The name "sound-level" implies all other definitions and experimental conditions. The name "sound-level" implies further, that the apparatus does not concern itself with the loudness of either pure tones or a combination of pure tones and sounds.

In this situation we must fall back on the above-mentioned principle of "ideal curves," so long as no universal and sufficiently simple equipment exists.

Our measurements show that the simplest system of "comparison-curves" consists of straight lines in the "octave-level diagram," showing a fall-off of 3db per octave from 125-9000 Hz.

E. Lübcke [13] has stated that the selection of such "comparison curves" must be affected by other considerations, especially hearing difficulties.

In order to economize on the writing-out of the "octave-level diagram," E. Lübcke [13] has further suggested that an apparatus like the above-suggested sound level meter be combined with octave-filters. This would add no new technical elements to the system of octave-filters and sound-pressure meters we have described.

If one then simplifies the comparison-curve principle to the extent that the peak value read off such such an apparatus becomes decisive, then there is no need of measuring the octaves separately and then reading off the peak values.

Finally, let us acknowledge that similar experiments were carried out in a dead room of the Institute, using an even sound-field, before our experiments with the diffuse soundfield began. The number of subjects was small. The apparatus did not conform to the necessary requirements as established by later researches. Above all, there were strong extraneous noises in the insulated room, so that the loudness comparisons were not unambiguous, at least at low frequencies. Let us note, however, that the shape of the curves obtained here showed a difference from the known curves of equal loudness for pure tones, in that a weak, monotone, but unmistakable fall-off was evident up to 4000 Hz.

We extend our most heartfelt thanks to the Deutsche Forschungsgemeinschaft for providing the wherewithal to complete these experiments.

Bibliography

[1] DIN 5045, Edition of March 1957

[2] Quietzsch, G. Objective and Subjective Loudness Measurement. Acustica 5 [1955], Supplement 1.

[3] Fletcher, H. and Munson, W.A. Loudness, its measurement, definition, and calculation. J. acoustic Soc. Amer. 4, [1932/33], 82.

[4] Thilo, H.G. and Steudel, U. Analysis of Noises and their connection with Loudness. Wiss. Veroff Siemens 14, [1935], 78.

[5] Beranek, L.L., Marshall, J.L., and Cudworth, L. Calculation and Measurements of the Loudness of Sounds. J. Acoust. Soc. Amer. 23 [1951], ?.

[6] Mintz, F., and Tyzzer, F.G. A loudness chart and octave band data of complex sounds. J. Acoust. Soc. Amer., 24, [1952], 80.

[7] Feldtkeller, R. and Zwicker, E. On the Loudness of Similarly-shaped sounds. Acustica 5, [1955], 303.

[8] Cremer, L., and Schreiber, L. On the different ways of representing acoustic spectra. Frequenz 10 [1956], 201.

[9] Stevens, S.S. Calculation of the Loudness of complex noise. J. Acoust. Soc. Amer. 28, [1956], 807.

[10] DIN 52 211.

[11] Cremer, L., and Lübcke, G. Sound classification through comparison of measured noise-analyses with normal curves. Report of 21/6/55 in the Franak-Committee on Loudness and noise measurement. (Soon to be published in the VDI-Berichte). See also Lubcke, E. On Noise Measurement. Frequenz, 12, [1958], 209.

[12] Jahn, G. Curves of equal loudness for octave-filtered noise. Report from the Institute for Electric and Building Acoustics at

Dresden. Reproduced and first distributed at the ISO-convention, Stockholm, July, 1958.

[13] Lübcke, E. Presentation at the VDI convention, Stuttgart, April 1958 (soon to be published in the VDI - Berichte). See also Lübcke, E. On Noise Measurement. Frequenz, 12 [1958], 209.